Assessment of Dural Arteriovenous Fistulae by Transcranial Color-Coded Duplex Sonography

Judith U. Harrer, MD; Octavian Popescu, MD; Hans H. Henkes, MD; Christof Klötzsch, MD

Background and Purpose**—**To study hemodynamic changes and to determine the value of contrast-enhanced transcranial color-coded sonography (TCCS) for the evaluation of dural arteriovenous fistulae (DAVF) before and after transcatheter embolization.

Methods**—**Twenty-four patients (mean age 61±11 years) with occipitally located DAVF were studied with contrast-enhanced TCCS using the transtemporal bone window in transverse-axial and coronal insonation planes. Blood flow velocity measurements of all depictable basal cerebral veins and sinuses were obtained before and after transcatheter embolization. Pretreatment and post-treatment flow velocity values were compared. Results of digital subtraction angiography (DSA) were compared with sonographic findings.

Results**—**Four of the 24 patients (17%) could not be studied because of an insufficient temporal bone window. In all remaining patients ($n=20$), draining veins/sinuses could be identified because of pathologically increased blood flow velocities with peak systolic flow velocities of >50 cm/s. Of the 27 draining vessels depicted by DSA, TCCS correctly identified 25 (93%): the basal vein (3 of 3), the straight sinus (3 of 3), the superior sagittal sinus (1 of 3), the transverse sinus (9), the sigmoid sinus (4), and the superior petrosal sinus (5/5). However, TCCS failed to depict supplementary drainage via cortical veins. After transcatheter embolization, mean reduction of blood flow velocity was 44±18% ($P<0.01$) compared with pretreatment values.

Conclusions**—**Contrast-enhanced TCCS is a promising technique for monitoring embolization of DAVF, follow-up after complete fistula occlusion, and may even be useful as a screening tool in patients with pulsatile tinnitus. **(*Stroke*. 2005; 36:976-979.)**

Key Words: arteriovenous fistula ■ central nervous system vascular malformations ■ contrast media ■ embolization, therapeutic ■ ultrasonography, Doppler, transcranial

Dural arteriovenous fistulae (DAVF) comprise ≈10% of all intracranial arteriovenous malformations.[1] DAVF are commonly located in the posterior cranial fossa, and some of them may have developed after sinus thrombosis.[1–3] The occipital artery and meningeal branches of the external carotid artery are the common feeders of DAVF, although less frequently, tentorial and dural branches of the internal carotid or vertebral artery may contribute to the blood supply of the fistula. Venous drainage usually comprises the transverse and sigmoid sinus, occasionally involving contralateral sinuses. Drainage into cortical veins carries a high risk of intracranial hemorrhage, nonhemorrhagic neurologic deficit, and death.[1,4]

In the past, several reports have been published showing that transcranial Doppler sonography as well as transcranial color-coded sonography (TCCS) enable evaluation of cerebral veins and sinuses.[5–9] In particular, power mode–based TCCS combined with the administration of ultrasound contrast agents allows improved depiction of intracranial veins, especially in the case of very low blood flow.[8–10] Although TCCS does not allow reliable differentiation between cerebral venous thrombosis and venous aplasia of the investigated segment, extensive thrombosis usually entails venous collateral flow with increased blood flow velocity and sometimes even reversed flow direction, which is directly assessable by TCCS.[5,6,10–12]

Diagnosis and follow-up of DAVF relies on digital subtraction angiography (DSA), although several magnetic resonance and computed tomography angiography studies have been published recently.[13,14] Extracranial and transcranial duplex sonography have been applied to study cavernous dural fistulae, but so far, noncavernous DAVF have only been investigated by means of indirect sonographic criteria such as the extracranially measured cerebral circulation time and the resistive index in the external carotid artery.[15–17]

The aim of the present study was to determine the value of contrast-enhanced frequency-based TCCS for the direct in-

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vestigation of hemodynamic changes in DAVF before and after transcatheter embolization.

Patients and Methods

Patients

Twenty-four patients (10 men, 14 women; mean age 61±11 years [±SD]; range 37 to 77 years) were included during a study period of 12 months. All patients were admitted to the neuroradiological department for selective embolization of a previously angiographically proven DAVF. All of these were located occipitally. Exclusion criteria were: uncontrolled hypertension (repetitive systolic blood pressure of >140 mm Hg or diastolic blood pressure of >85 mm Hg during admission or previously known); severe heart failure (New York Heart Association III-IV); galactosemia; pregnancy or lactation; and previous allergic reactions to the administered ultrasound contrast agent (Levovist; 300 mg/mL; Schering). Each patient gave informed consent, and the performed investigations were in accordance with institutional guidelines.

Transcranial Color-Coded Duplex Sonography

TCCS investigators (O.P., C.K.) were blinded to the results of the DSA. Each patient was investigated before and within 7 days after the first embolization. Frequency-based TCCS was performed using an Acuson XP 128/10 (Acuson) with the corresponding 2-MHz phased-array transducer. Levovist, a galactose-based ultrasound contrast agent, was administered into an antecubital vein in repetitive bolus fractions of 2 mL (600 mg) to improve visualization of cerebral veins; a maximum of 2.5 g was given. To further increase sensitivity for low venous blood flow, pulse repetition frequency was reduced, a low wall filter was selected, and color gain was increased taking interindividual differences such as quality of the temporal bone window and contrast effect into account. Cerebral veins and sinuses were assessed in transverse-axial and coronal insonation planes using the ipsilateral temporal bone window. Transtemporally, the deep middle cerebral vein, the basal vein of Rosenthal, the straight sinus, the posterior part of the superior sagittal sinus, and the contralateral transverse sinus can commonly be assessed in up to 90% of cases.[8,11,18] Additional spectral nonangle corrected Doppler was performed to obtain flow velocity values (peak systolic velocity, end-diastolic velocity) of all depictable veins. TCCS-based diagnosis of a DAVF was established when at least 1 of the following criteria was present: detection of increased venous blood flow velocity according to the criteria published by Baumgartner,[8,9] the detection of reverse venous flow, or the detection of sinuses, which commonly are not depictable by TCCS (sigmoid sinus, superior/inferior petrosal sinus, inferior sagittal sinus). Insonation of these was attempted in each case via the contralateral temporal bone window using the transverse sinus and the petrous bone as anatomical lead for the sigmoid sinus, and again the petrous bone as leading structure for the superior/inferior petrosal sinus with stronger downward tilt for depiction of the inferior petrosal sinus. Insonation of the inferior sagittal sinus was attempted as described by Baumgartner.[8]

Treatment

Selective cerebral DSA was performed to display feeding arteries and draining veins. After femoral puncture, all 4 extracranial brain supplying vessels were catheterized, and ≈100 mL of an iodinated nonionic contrast agent (Solutrast 300; Iopamidol; Amersham) was administered to display the vessels. In 4 patients, a partial thrombosis of the transverse sinus (n=3) or sigmoid sinus (n=1) was present. For DAVF embolization, thrombogenic platinum fiber coils, polyvinyl alcohol particles, and bucrylate were used.

Data Analysis and Statistics

Results of TCCS regarding detection of draining veins were compared case-wise with DSA. Blood flow velocities measured by means of TCCS before and after the embolization were compared with a *t* test. A $P \leq 0.05$ was considered statistically significant.

TABLE 1. Detection of Ipsilateral, Nondraining Veins/Sinuses in 20 Patients Before Endovascular Treatment

Veins/Sinuses	DSA	TCCS	Percentage of Vessels Identified by TCCS	Peak Systolic Flow Velocities (cm/s; mean±SD)
Deep middle cerebral vein	20	17	85	15±3
Basal vein	17	15	88	18±2
Straight sinus	17	9	53	23±3
Superior sagittal sinus	17	. . .	0	. . .
Transverse sinus	8	6	75	29±4

Results

TCCS: General

Four of the 24 patients (17%) could not be examined by TCCS because of an insufficient temporal bone window despite ultrasound contrast agent application. In the remaining 20 patients, the deep middle cerebral vein could be detected in 85%, the basal vein in 88%, the straight sinus in 53%, and the transverse sinus in 75% (Table 1). The superior sagittal sinus (n=1), the sigmoid sinus (n=4) and the superior petrosal sinus (n=5) could only be depicted in patients who exhibited fistula drainage into these particular sinuses. Abnormally increased blood flow velocities compared with Baumgartner's normal values were found in all patients in at least 1 cerebral vein or sinus.[8,9] Table 2 shows the maximum flow velocities in the respective draining veins.

TCCS: Comparison With DSA

In 20 patients, angiography depicted 27 draining veins/sinuses. By means of TCCS, 25 of 27 draining veins/sinuses (93%) could be detected (Table 2). In 5 patients, angiography revealed additional cortical drainage, which could not be demonstrated by TCCS in any case. Analysis of flow velocities of draining veins as well as veins not contributing to the drainage of the DAVF showed an increase of flow velocities from cranial to caudal veins/sinuses (Tables 1 and 2). Figures 1 and 2 show a TCCS image and the corresponding digital subtraction angiogram of a patient with a DAVF draining into the deep middle cerebral vein and into the basal vein.

TCCS: Post-Treatment

DAVF embolization was uncomplicated in all patients. Flow velocities in draining veins decreased by a mean of 44±18%

TABLE 2. Detection of DAVF-Draining Veins/Sinuses in 20 Patients Before Endovascular Treatment

DAVF-Draining Veins/Sinuses	DSA	TCCS	Percentage of Vessels Identified by TCCS	Peak Systolic Flow Velocities (cm/s; mean±SD)
Basal vein (reverse flow)	3	3	100	54±6
Straight sinus (reverse flow)	3	3	100	58±6
Superior sagittal sinus	3	1	33	63±7
Transverse sinus	9	9	100	69±8
Sigmoid sinus	4	4	100	87±9
Superior petrosal sinus	5	5	100	96±13

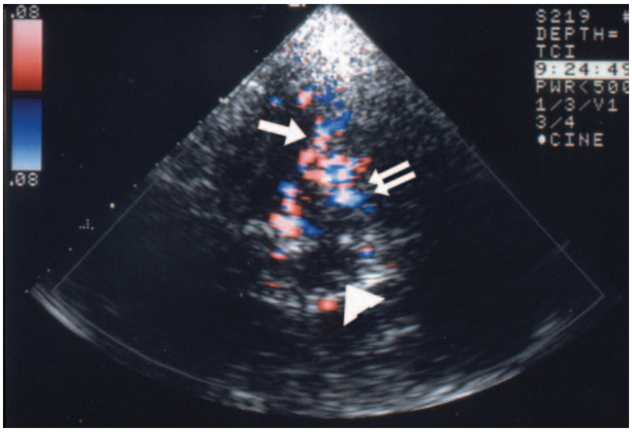

Figure 1. Transtemporal imaging of an occipitally located DAVF draining into the deep middle cerebral vein (arrow) and into the basal vein (double arrow). The basal vein surrounds the brain stem, which is depicted as a butterfly-shaped structure (arrowhead).

($P<0.01$) after embolization when compared with pretreatment values. After treatment, TCCS failed to detect 6 of 25 veins/sinuses that were depictable before embolization, so that of these, no post-treatment flow velocity measurements could be obtained.

Discussion

In recent years, TCCS has been applied mainly to investigate cerebral arteries.[19–21] Venous transcranial sonographic examination is hampered by the low venous blood flow velocities and occasionally by problematical insonation angles. However, there is an increasing number of studies proving TCCS to be feasible for investigation of cerebral veins and sinuses in normal volunteers as well as pathological conditions such as sinus thrombosis.[8–11,18,22,23]

The results of our study regarding detectability of normal blood flow in the deep middle cerebral vein, in the basal vein, and in the transverse sinus were comparable to previous studies, yet the straight sinus (53%) and the superior sagittal sinus (5%) were depicted considerably less frequently, which is most likely because only the temporal but not the nuchal approach was used for investigation.[8,18] Applying the temporal bone window, both sinuses are insonated with an angle of ≈90°, resulting in very low Doppler shifts that are hardly detectable by frequency-based ultrasound mode. Comparable to a study by Baumgartner, we found flow velocities to be highest in the transverse sinus followed by the straight sinus, and lower in the basal vein and deep middle cerebral vein, which is most likely attributable to the larger vessel diameter and increasing demand of blood flow in more caudal cerebral venous vessels.[8]

Several case reports and 1 systematic study have described imaging or measurement of pathologically increased venous flow velocities of carotid-cavernous fistulae.[15,24,25] Furthermore, neurosonography has long been applied for arterial investigation of DAVF.[26,27] However, a venous study has not yet been published. Our results demonstrate an increased flow velocity in at least 1 cerebral vein or sinus in all DAVF patients with a sufficient bone window ($n=20$). Drawing conclusions from our study in conjunction with previously published reports, any venous peak systolic flow velocity exceeding 50 cm/s should be regarded as pathological and lead to further neuroradiological investigations.[7–9] Although flow velocities up to 81 cm/s have been measured in the cavernous sinus, which was not investigated in this study, even in this complex region, mean flow velocities lay ≈25 cm /s.[28] For the first time, the sigmoid sinus and the superior petrosal sinus could be depicted by TCCS because of the pathologically high flow velocities in DAVF draining veins along with the administration of an ultrasound contrast agent. A certain drawback of the technique is the failure to depict additional cortical venous drainage, especially because drainage into cortical veins implies a significantly increased risk of cerebral hemorrhage attributable to venous hypertension.[1,29]

After partial embolization of the DAVF, a distinct reduction in venous flow velocities was observed in all former draining veins and sinuses. Further studies are needed to assess whether TCCS is a useful follow-up tool to depict recanalization of fistulae, which occasionally occurs after complete DAVF embolization. TCCS follow-up could be complemented by the measurement of the global cerebral circulation time, which is typically shortened in DAVF and may be obtained by means of extracranial Doppler sonography.[16]

As in other contrast-enhanced TCCS studies, the rate of unexaminable patients (17%) resulting from an insufficient

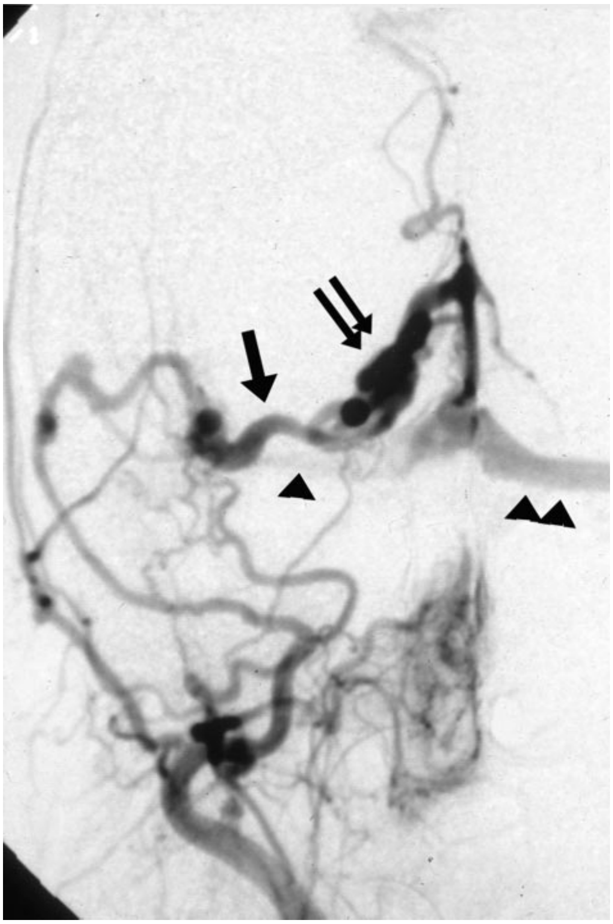

Figure 2. The corresponding digital subtraction angiogram in anteroposterior view shows the deep middle cerebral vein (arrow) and the basal vein (double arrow) as draining vessels of the fistula. Because of partial thrombosis of the ispilateral transverse sinus (arrowhead), further drainage occurs via the contralateral transverse sinus (double arrowhead).

bone window despite the application of an ultrasound contrast agent is a further disadvantage of the technique. However, this is certainly outweighed by its relatively easy, fast, and patient-comfortable application that, although using a contrast agent, has hardly any relevant side effects.[30,31]

The informational value of contrast-enhanced TCCS is too low to characterize the complete angioarchitecture of a DAVF. Unquestionably, arterial investigation is of further important informational value for the treatment of DAVF; however, this was not the subject of this study. Nevertheless, experienced investigators will certainly detect typical ultrasonographic features if a DAVF is present in a regular TCCS investigation of the intracranial arteries. Because application of a routine set-up for investigation of the arterial system will not allow demonstration of normal cerebral veins and sinuses, depiction of these would require spectral analysis to clarify whether increased venous blood flow was present in the respective vessels. This is also true for the depiction of veins/sinuses that are usually undetectable in healthy adults as, for example, the sigmoid and the superior petrosal sinus, as well as for the depiction of reverse flow in cerebral veins and sinuses, indicating venous collateral flow.

Summary

In this study, we have shown for the first time that contrast-enhanced TCCS enables imaging and measurement of pathologically increased flow velocities of DAVF-draining cerebral veins and sinuses as well as flow reduction after effective transcatheter embolization. Therefore, TCCS might be a valuable follow-up technique for DAVF patients, avoiding x-ray exposure and possibly useful particularly for patients in whom repeated application of iodinated contrast agents is to be precluded. Additional investigations will have to show whether contrast-enhanced TCCS alone is sufficient to exclude a DAVF in patients with pulsatile tinnitus.

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